Naval Research Laboratory
Stennis Space Center, MS 39529-5004

NRL/MR/7174--96-7726

Environmental Measurements and Observations in Support of the Naval Research Laboratory's High Frequency Acoustic Coherence Experiments, Panama City 1995

CHRISTINE T. MIRE
ROGER W. MEREDITH

Ocean Acoustics Branch
Acoustics Division

September 13, 1996

REPORT DOCUMENTATION PAGE

Form Approved
OBM No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 13, 1996

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
Environmental Measurements and Observations in Support of the Naval Research Laboratory's High Frequency Acoustic Coherence Experiments, Panama City 1995

5. FUNDING NUMBERS
Job Order No. 571-6861-00
Program Element No. 0602435N
Project No.
Task No. UW-35-2-05
Accession No.

6. AUTHOR(S)
Christine T. Mire and Roger W. Meredith

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Research Laboratory
Acoustics Division
Stennis Space Center, MS 39529-5004

8. PERFORMING ORGANIZATION REPORT NUMBER
NRL/MR/7174--96-7726

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Naval Research Laboratory
Acoustics Division
Stennis Space Center, MS 39529-5004

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

From 30 March to 19 April 1995, the Naval Research Laboratory conducted a series of high frequency acoustic coherence measurements in the shallow-water (6–12 m) coastal environment off Panama City Beach, FL. This report contains descriptions of the equipment used to collect the data, the data quantity and quality, plots and tabulations, and an analysis of the oceanographic environment in which the acoustic data were collected. From 30 March to 22 April, wind speed and direction, air temperature, barometric pressure, and solar irradiation were collected every 15 min. Oceanographic measurements were taken as sea conditions permitted from 5 April to 19 April. A total of 29 CTD profiles and two CTD time series of 2 and 4 days each were collected. Wave spectra and small scale temperature variations were also collected during each acoustic run.

Weather and oceanographic conditions were typical of the northeastern Gulf of Mexico during spring. In general, air and sea temperatures rose over the course of the experiment except during the passage of cold fronts. Water column temperatures were close to isothermal and had not developed the typical late spring, mid-depth thermocline. However, changes in the water mass produced by effluence from St. Andrews Bay during falling tides were evident on calm days in the temperature, salinity, and sound speed time series. On at least three occasions, internal wave activity was also associated with these water mass changes.

14. SUBJECT TERMS
MCM sonar systems designs, high frequency acoustics, spatial and temporal coherence

15. NUMBER OF PAGES
41

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

CONTENTS

I. INTRODUCTION

From 30 March to 19 April 1995 the Naval Research Laboratory (NRL) conducted a series of high frequency acoustic coherence measurements in the shallow-water (6-12 m) coastal environment off Panama City Beach, Florida.[1] To support the acoustic data, measurements were made of surface weather, wave spectra, and water column properties. This report contains descriptions of the equipment used to collect the data, the data quantity and quality, plots and tabulations, and an analysis of the oceanographic environment in which the acoustic data were collected. It is our intention to interpret the collected environmental data and where required, extend this information along with prior regional analyses to provide a reasonable description of the acoustic environment on days when no environmental data were obtained. Dates and times are reported as Central standard time and directions are relative to magnetic north (M).

II. GENERAL AREA DESCRIPTION

An excellent description of the general area is given in Salsman and Ciesluk, 1978. The facts pertinent to this experiment are summarized from this extensive report. Panama City is located on the eastern shores of the St. Andrews Bay system. Panama City Beach, where this experiment was conducted, is located on the western barrier island of the bay system (Figure 1).

Two entrance channels connect St. Andrews Bay with the Gulf of Mexico, one is a man-made ship channel and the other a natural bay entrance. The man-made entrance is 6.4 km (4 miles) southwest of Panama City and approxi-

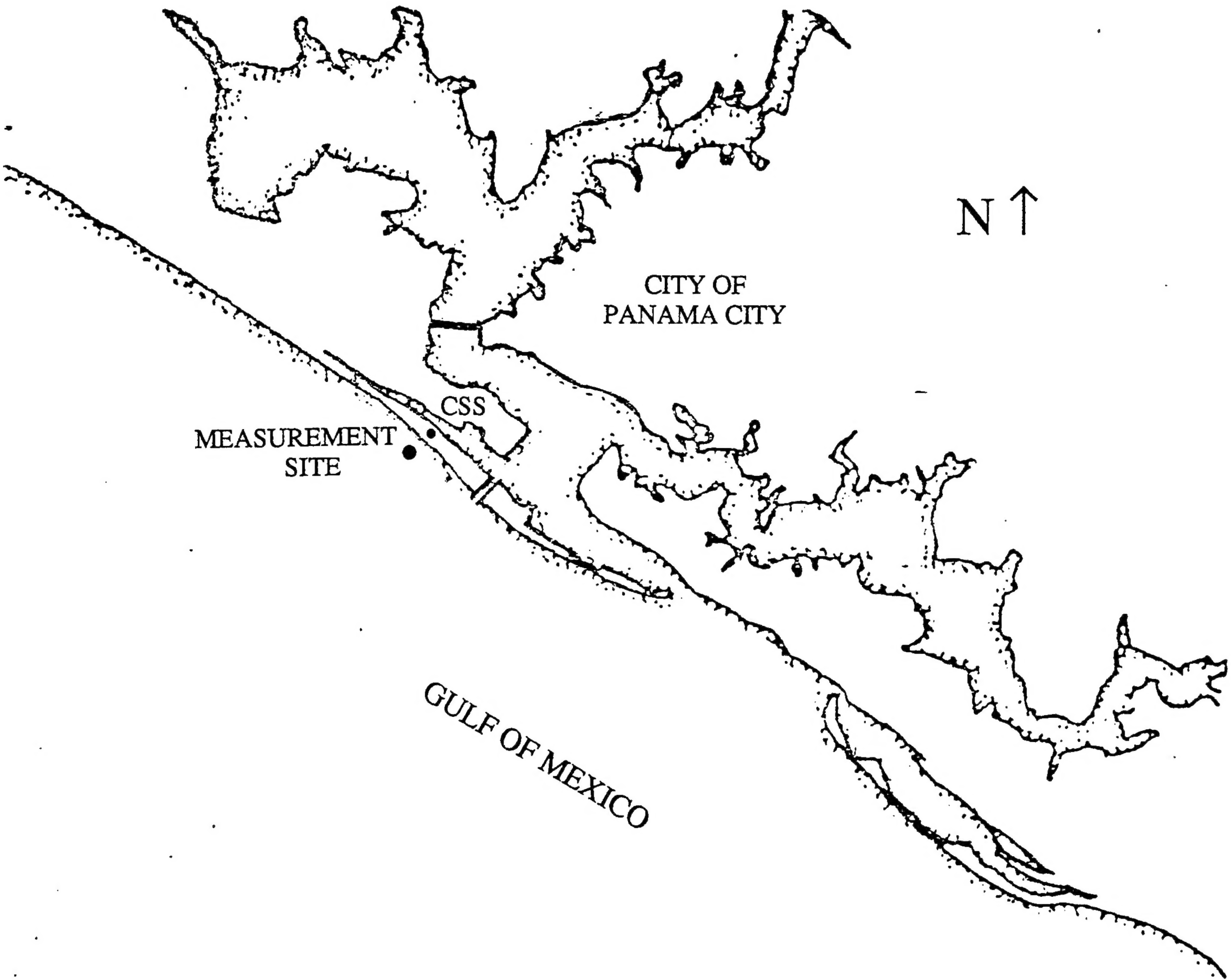


Figure 1. Panama City experimental location and surrounding inland waterways (from Salsman and Ciesluk, 1978).

mately 3.2 km (2 miles) southeast of the measurement location. The natural bay entrance lies another 8 km (5 miles) to the southeast of the man-made ship channel. Features of the northeastern Gulf shoreline include white sand beaches extending over 160 km (100 miles) to the east and west of Panama City. The coastal bathymetry consists of shallow sand bars just offshore beyond which the bottom dips to 15 m within 1.6 km (1 mile) of the beach. The local seafloor is characteristically flat and featureless, with sand dominating the nearby gulf and shores of St. Andrews Bay. Beaches are composed almost exclusively of fine quartz grains. This fine sand extends out across the shallow bars and down to water depths of 15 or 18 m.

Gulf coast tidal oscillations and corresponding currents in this particular area are mainly diurnal in period, small in amplitude, and very susceptible to modification by wind and weather.[2-4] Currents produced from tidal flows are rotary in nature, with the long axis of the ellipse parallel to the shore, and have surface and subsurface currents opposing each other.[2, 5, 6] The primary mechanism of surface water transport in these local coastal waters is wind-induced currents. Rotary tidal currents have also been detected in periods of little or no wind.[2, 5-7] There do not appear to be any permanent or semipermanent unidirectional currents occurring in the nearby coastal area. Predicted tidal amplitudes are shown in Figure 2 and are listed in Table 1. The tidal cycle is completed in a lunar day (24.8 hours), taking approximately 14 hours to rise and 11 hours to fall. Data collection times for acoustic data and CTD profiles are superimposed on the predicted tidal curves. Times of high and low

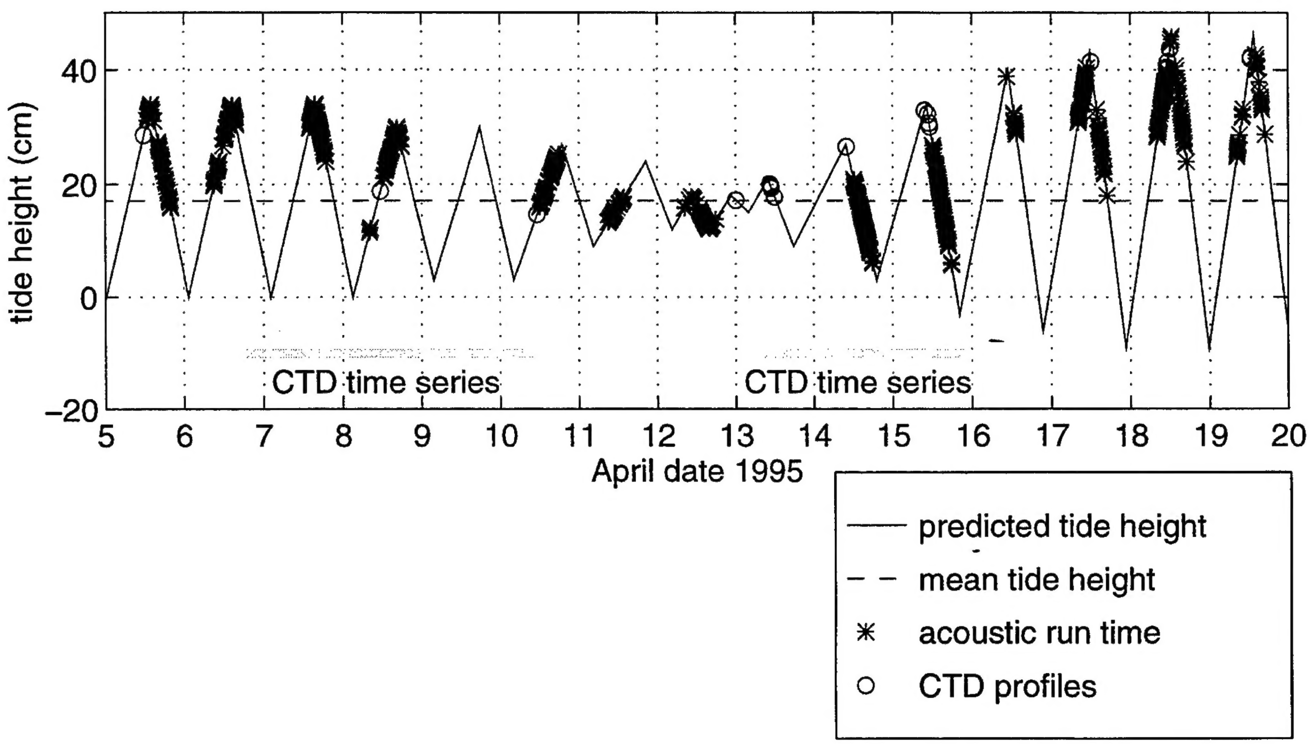


Figure 2. Predicted tidal heights for Panama City annotated with acoustic run times, CTD profile collection times and CTD time series.

Table 1. Predicted times of high and low water and tidal heights for Pensacola, Fl, 1995. Times are Central Standard time. High and low water at Panama City occur 44 mins earlier. Add 1 hour to predicted times for daylight savings.

March Date	Local Time	Tidal Height (cm)
1	810	3
2	2	18
2	750	6
2	1239	9
2	1808	6
3	122	15
3	650	12
3	1235	15
3	2024	6
4	1257	18
4	2224	3
5	1331	21
6	8	0
6	1413	24
7	131	0
7	1501	27
8	239	-3
8	1555	27
9	337	-3
9	1653	30
10	428	-3
10	1753	30
11	513	-3
11	1851	30
12	553	-3
12	1948	30
13	626	-3
13	2046	27
14	652	0
14	2147	24
15	705	6
15	2257	21
16	656	9
16	1135	12
16	1656	9
17	29	18
17	610	12
17	1120	18
17	1905	6
18	1140	24
18	2053	0
19	1216	30
19	2229	-3
20	1303	34
20	2355	-6
21	1356	37
22	112	-9
22	1455	40
23	222	-9
23	1558	40
24	324	-9

March Date	Local Time	Tidal Height (cm)
24	1706	37
25	419	-6
25	1818	34
26	505	-3
26	1953	30
27	538	3
27	2054	24
28	551	9
28	2226	21
29	533	12
29	1047	15
29	1715	9
30	26	18
30	430	15
30	1058*	21
30	1855	6
31	1052	24
31	2012	3

April Date	Local Time	Tidal Height (cm)
1	1118	27
1	2118	3
2	1150	30
2	2220	0
3	1226	34
3	2321	0
4	1317	34
5	21	0
5	1353	34
6	120	0
6	1443	34
7	214	0
7	1536	34
8	302	0
8	1634	30
9	342	3
9	1738	30
10	413	3
10	1854	27
11	433	9
11	2029	24
12	432	12
12	1031	18
12	1552	12
12	2238	18
13	352	15
13	948	21
13	1746	9
14	952	27
14	1908	3
15	1017	34

April Date	Local Time	Tidal Height (cm)
15	2019	-3
16	1055	40
16	2127	-6
17	1140	43
17	2234	-9
18	1230	46
18	2340	-9
19	1323	46
20	42	-9
20	1418	43
21	139	-6
21	1516	40
22	228	-3
22	1616	34
23	302	3
23	1723	27
24	315	9
24	1858	21
25	257	12
25	955	21
25	1648	15
25	2204	18
26	137	15
26	925	24
26	1813	9
27	930	30
27	1909	6
28	948	34
28	1956	3
29	1014	37
29	2040	0
30	1043	40
30	2124	-3

water have been corrected in Figure 2 from Pensacola, FL predictions according to the NOAA tables. [3]

Water column characteristics vary in time, location, and season. Generally the water temperatures are isothermal from summer through fall and winter, with temperature decreasing at all depths. The passage of cold fronts serves to mix the water column and drain heat from it during the fall and winter months. Warming of the surface waters during spring causes a thermocline near mid-depth which disappears whenever storms bring heavy seas to the area. Nearshore waters then become well mixed but it takes only a few tidal cycles to re-establish a thermocline after seas have calmed. Salinity is characteristically high (> 34ppt), with weak vertical gradients and some seasonal variability. Typical changes of only 1 to 1.5 ppt are reported between surface and subsurface waters. Salinities of 31 ppt have been recorded at the surface during the passage of the "tide line". Internal waves frequent the coastal waters during spring and early summer and are related to the spring thermocline and associated density gradient.[2]

This experiment was conducted during the gulf coast's late springtime conditions and therefore has characteristics of both winter and summer weather conditions. Quoting from reference 2: "This area lies within a climatic belt known as the horse latitudes... and exhibiting tropical characteristics during some periods (especially summer), and vacillating between temperate and tropic conditions during other seasons. The typical winter weather pattern is dominated by extra-tropical frontal systems, which periodically sweep down from the central

plains. Prior to the arrival of each front, weather is generally warm and humid, and winds blow from a southerly to southeasterly direction, gradually increasing in speed and causing local seas to build. Frontal passage(s) are usually accompanied by strong winds, heavy seas, and rainshowers. The winds shift abruptly to a northwesterly or northerly direction after a frontal passage. Rain then stops, skies clear, air temperature and humidity decrease rapidly, and seas gradually begin to subside. The area then enjoys several days of clear, cool weather, light winds, and minimal wave action as a ridge of high pressure migrates eastward toward the Atlantic Ocean.

Typical summer weather pattern is usually dominated by the so-called Bermuda High, a more-or-less permanent high pressure cell which is centered in the Atlantic Ocean off the Carolinas. The gentle clockwise flow around this cell brings warm moist air to the entire eastern half of the nation. At Panama City, surface winds blow primarily from easterly and southeasterly directions. During the day, land areas are heated by the sun, causing the overlaying air to warm, lighten, and ascend. A local sea breeze then sets in, causing the humidity to rise and local seas to become choppy. Rising air cools and condenses, forming cumulus and cumulonimbus clouds, which produce showers or thunderstorms practically every afternoon. Following sunset, these clouds usually dissipate, the sea breeze subsides, and local waters become smooth."[2]

III. ENVIRONMENTAL MEASUREMENTS

A. Surface Weather Data

Atmospheric measurements were made from 30 March to 22 April using an Enviro-Labs, Inc., Weather Logger Model DL-120-C1-W8. The logger records data from a Young anemometer, a Belfort barometric pressure sensor, a Belfort solar radiation sensor, and an Enviro-Labs temperature probe. The system was mounted on a 10 m tower approximately 100 m from the surf (Fig. 3). The weather system was calibrated by The Standard and Calibration Lab of Sverdrup Technology Inc, at Stennis Space Center Mississippi in March 1995. The sensor specifications are given in Table 2. Every 15 minutes, the weather logger averaged data for two minutes and logged the average. The values for the peak wind speed occurring during the two minute averages and its direction were also logged. The wind speeds and directions obtained at this location were affected by residential structures to the north, east and west. Wind speed and direction

Table 2. Meteorological sensor specifications.

WIND SPEED	*AIR TEMPERATURE*
Range: 0 to 50 m/s Resolution: 0.1 m/s Accuracy: ±0.5 m/s	Range:-30 to + 50°C Resolution: 0.1°C Accuracy: ±1.0°C
WIND DIRECTION	*BAROMETRIC PRESSURE*
Range: 0 to 359° Resolution: 1.0° Accuracy: ±4.0°	Range: 21.8-28.5 inches Hg Resolution: 0.3 % Accuracy: ±0.2%

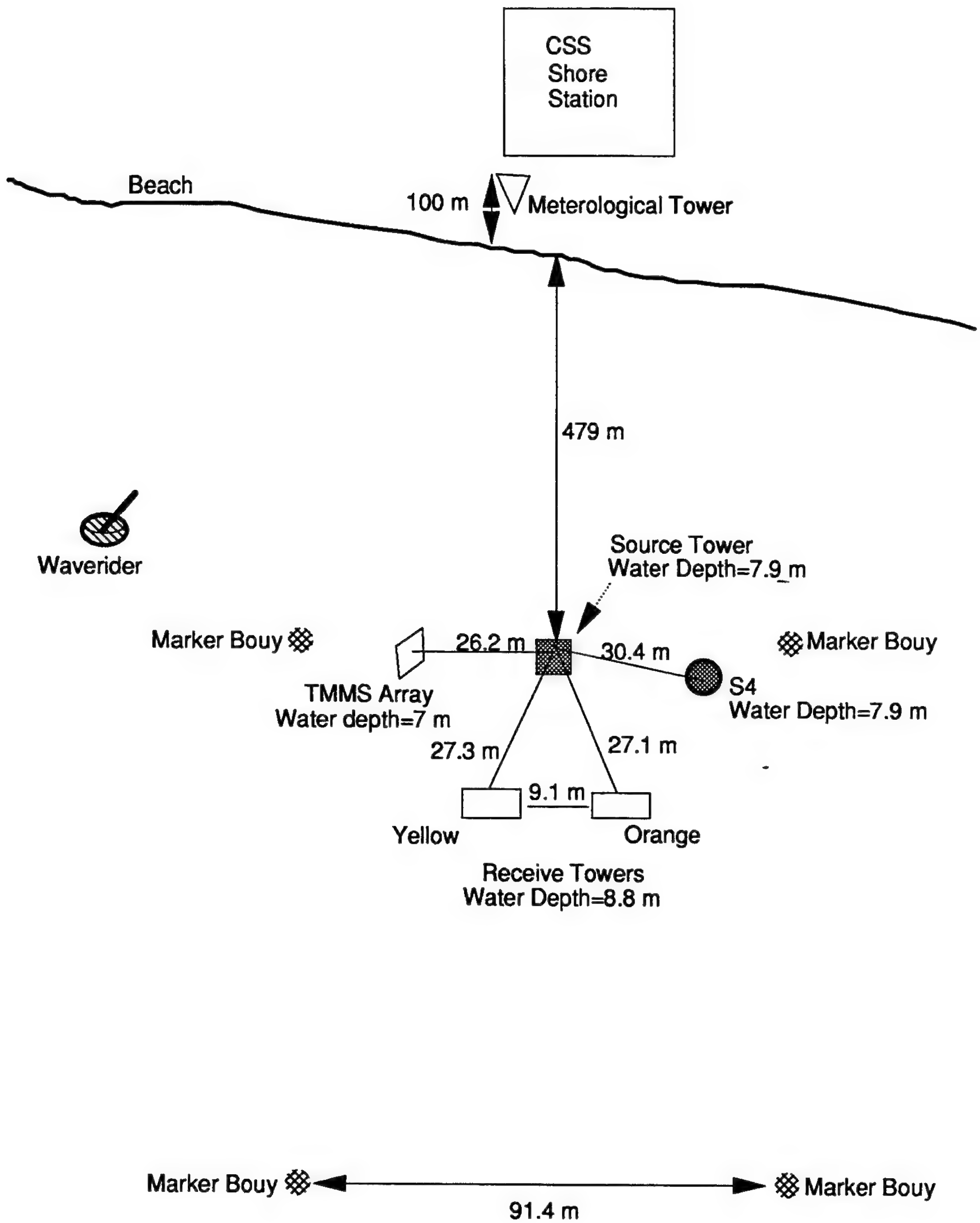


Figure 3. Panama City experiment geometry illustrating oceanographic sensors and acoustic towers in their initial positions on 30 March, 1995.

from the south should be accurate. However, general trends in weather conditions and related wind velocity can be interpreted from these records. Figure 4 shows the recorded surface weather data.

B. CTD Profiles and Time Series

Conductivity-temperature-depth (CTD) profiles were collected aboard a 60 ft dive boat when weather and sea conditions permitted. A Seabird SeaCat CTD with a fixed sampling rate of 2 Hz was used to acquire data. Potential temperatures are reported and differ from in situ temperatures by -0.02°C for the depths and salinities encountered during this experiment. Probe specifications are given in Table 3. This instrument was calibrated in March 1994 by SeaBird Electronics. The calibration constants were programmed into the instrument so that output data is correct. A total of 29 CTD profiles were collected over a period of 9 days. Profiles were taken within the buoy field marking the experimental instrumentation and at the inlet east of the buoy field (Figure 1). Temperature, salinity, and sound speed profiles are shown in Figures 5 through 7. All profiles on any given day were collected over less than an hour and a half time period and are very similar.

Table 3. SeaBird SeaCat specifications.

SENSOR	RANGE	SENSITIVITY
Potential Temperature	-5 to +35°C	±0.01°c
Conductivity	0-70 mmho/cm	±0.01 mmho/cm
Pressure	15-200 psia	±5% of full scale

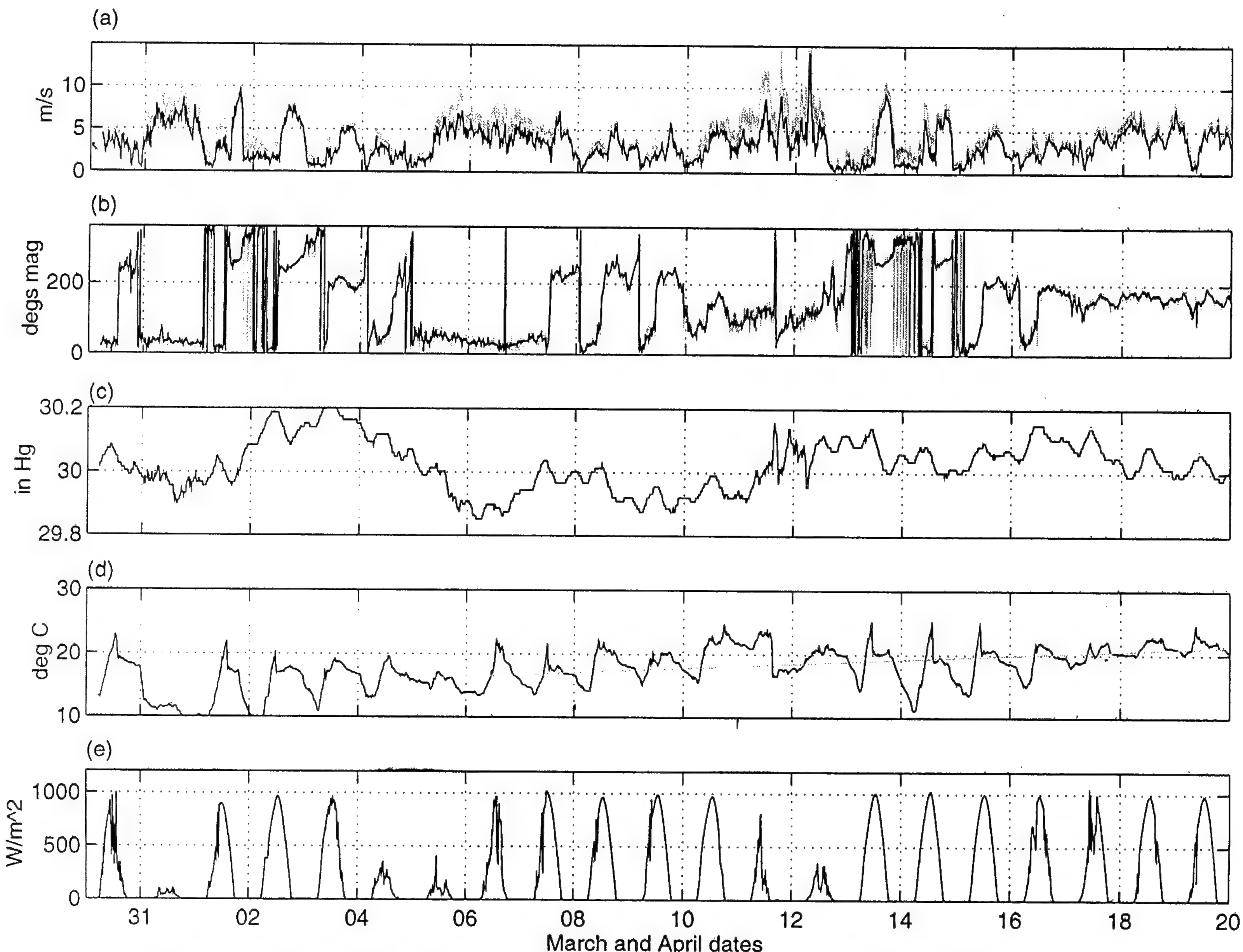
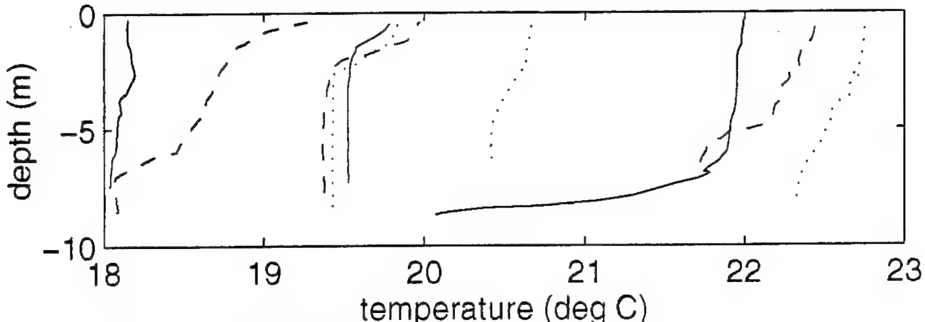


Figure 4. Surface weather data during 1995 Panama City high frequency phase stability measurements. (a) Average wind speed (black) and peak wind speed (gray), (b) average wind direction (black) and peak wind direction (gray), (c) barometric pressure, (d) air temp and trend (gray), and (e) solar irradiation.



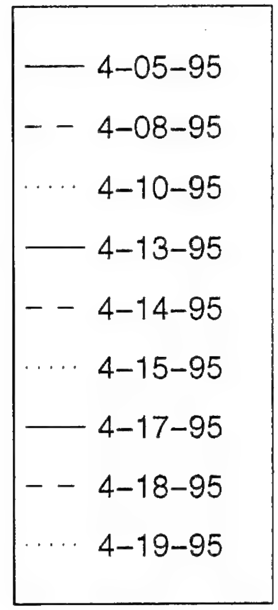


Figure 5. Temperature profiles.

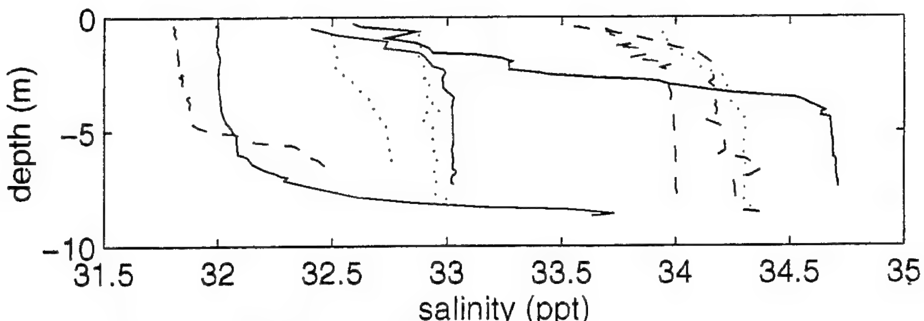


Figure 6. Salinity profiles.

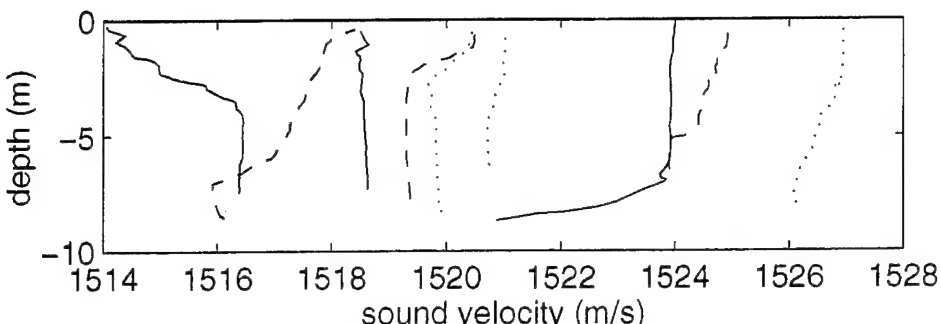


Figure 7. Sound velocity profiles.

Therefore only one representative profile was plotted for each day CTD data were collected. It should be noted that CTD profiles were collected during different phases of the tidal cycle on different days with varying seas and weather conditions. The collection of profiles indicates the range of values that were encountered during the experiment.

Two CTD time series were also collected. A Seabird CTD was mounted 3 m (10 ft) above the ocean bottom on the acoustic source tower that was approximately 462 m (1517 ft) offshore (Fig. 3). Each value in the recorded data represent a 30 second average value from each sensor (2 Hz sampling rate). The first time series was collected from 0925 on 6 April to 1120 on 10 April. The second time series was collected from 0944 on 13 April to 0004 on 16 April. Plots of temperature, salinity, and sound velocity for each time series are shown in Figures 8 through 13.

C. Wave Rider Data

A Waverider model F1 buoy was used to measure wave height during intermittent periods from 30 March to 11 April (Figure 14). Specifications of this device are given in Table 4. Waverider file collection times, and associated Thermal Microstructure Measurement System (TMMS) and acoustic measurement file numbers are given in Table 5. The passage of a strong cold front on the 11th produced rough seas which eventually flooded the Waverider buoy. Data were collected with a sample rate of 10 Hz and were post-processed with a 1 second running average. Waverider data were collected during acoustic runs

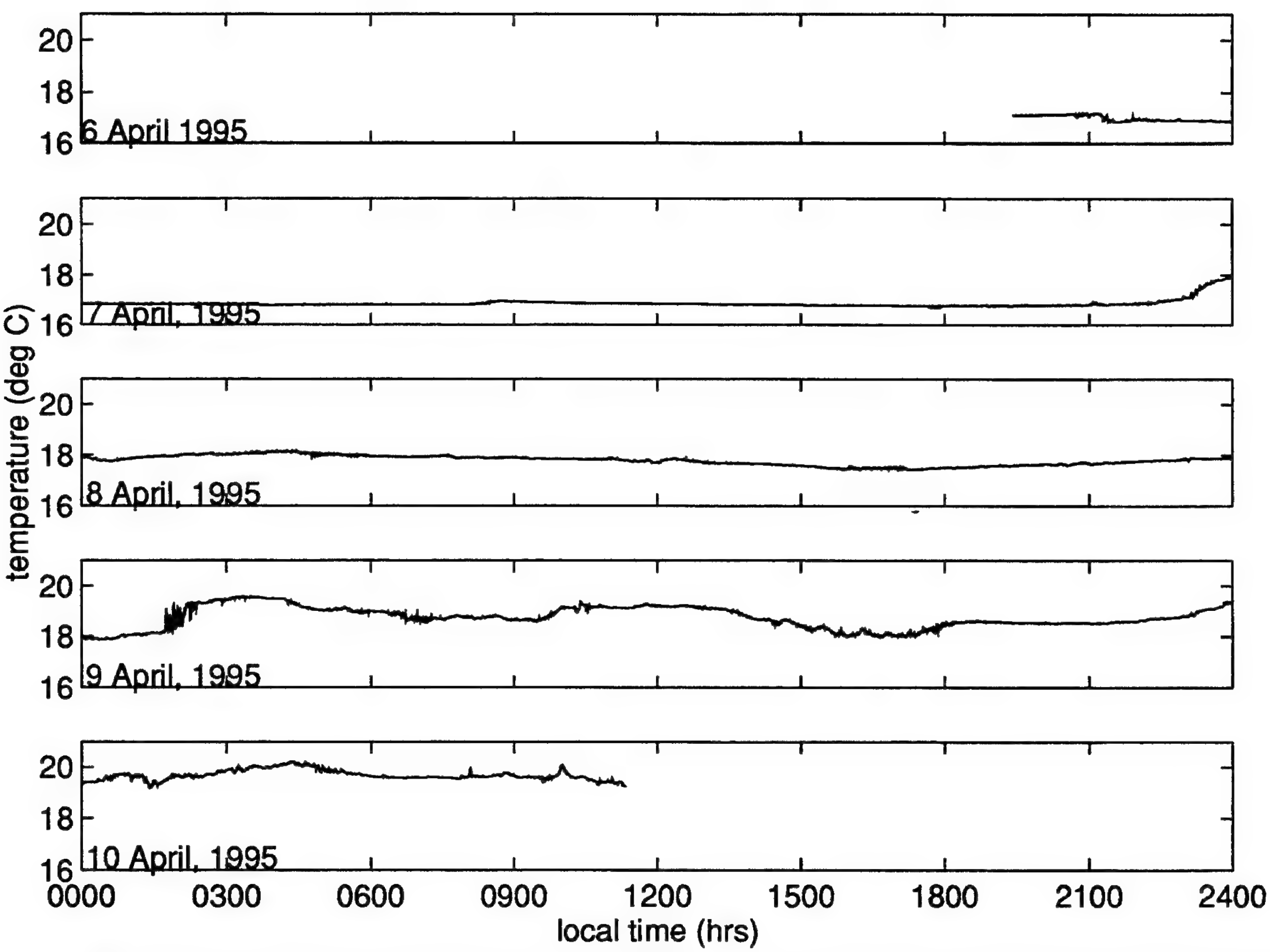


Figure 8. Temperature time series from CTD mounted on the source tower for 6–10 April 1995.

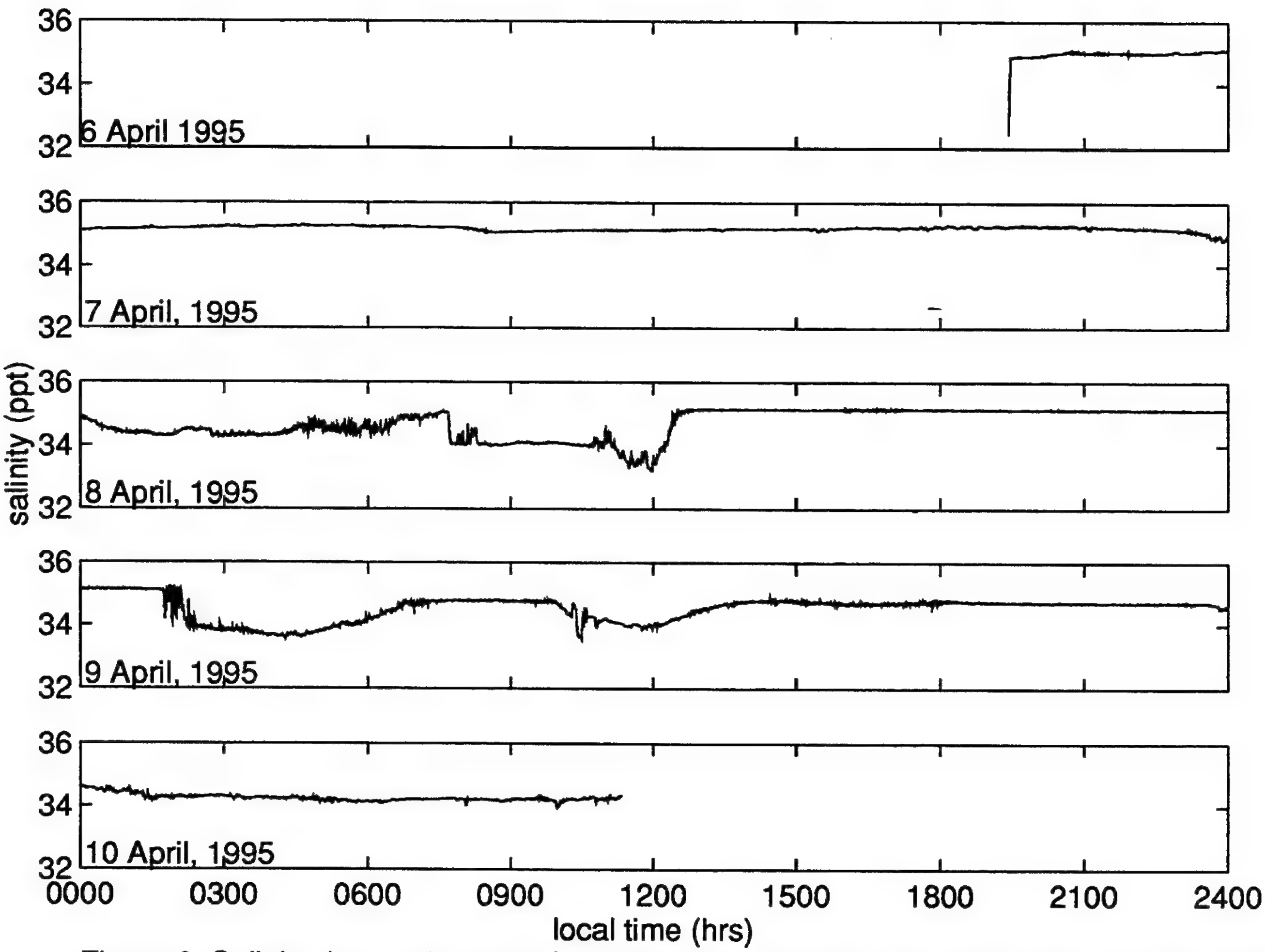


Figure 9. Salinity time series from CTD mounted on the source tower for 6–10 April 1995.

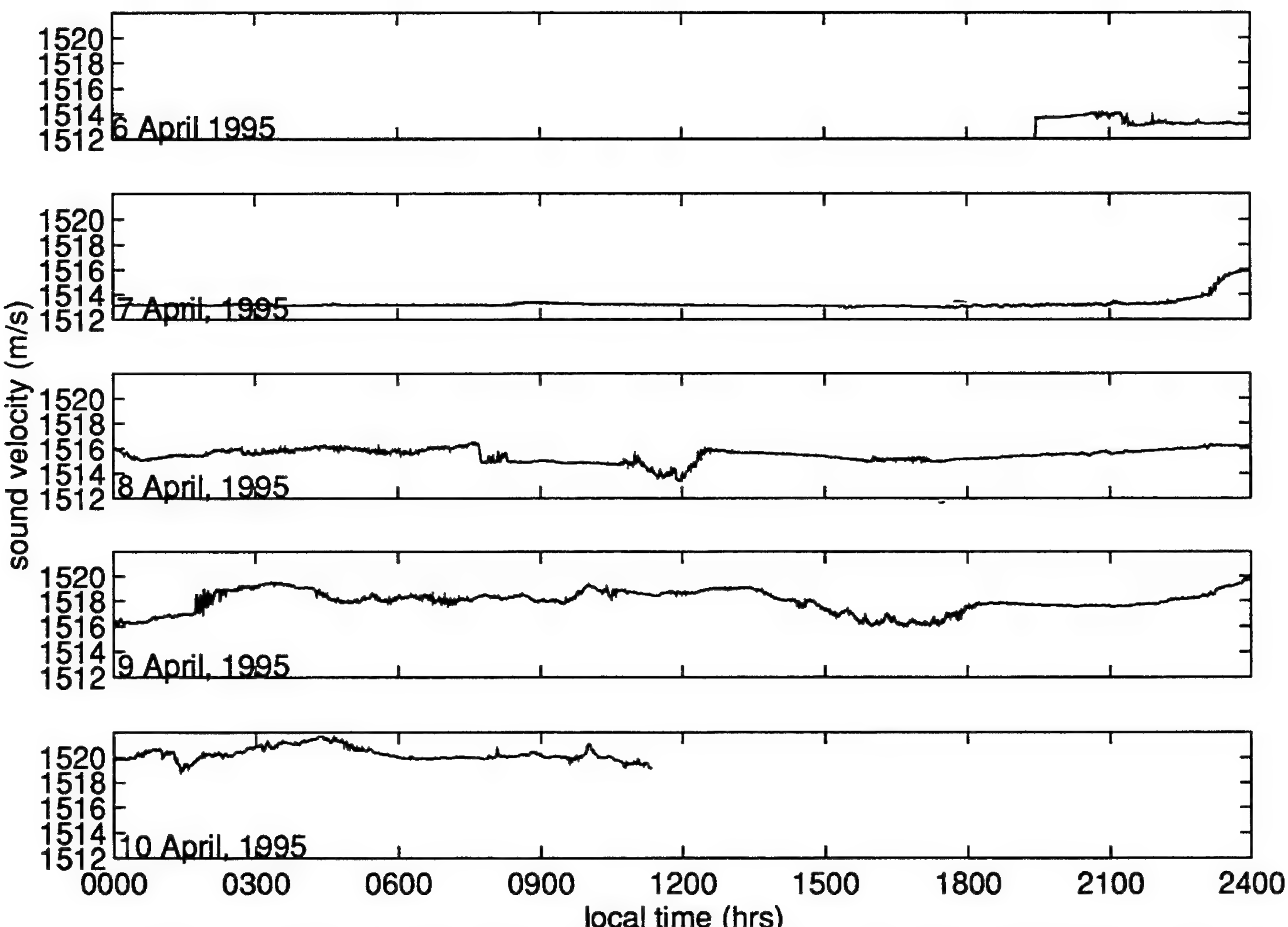


Figure 10. Sound velocity series from CTD mounted on the source tower for 6–10 April 1995.

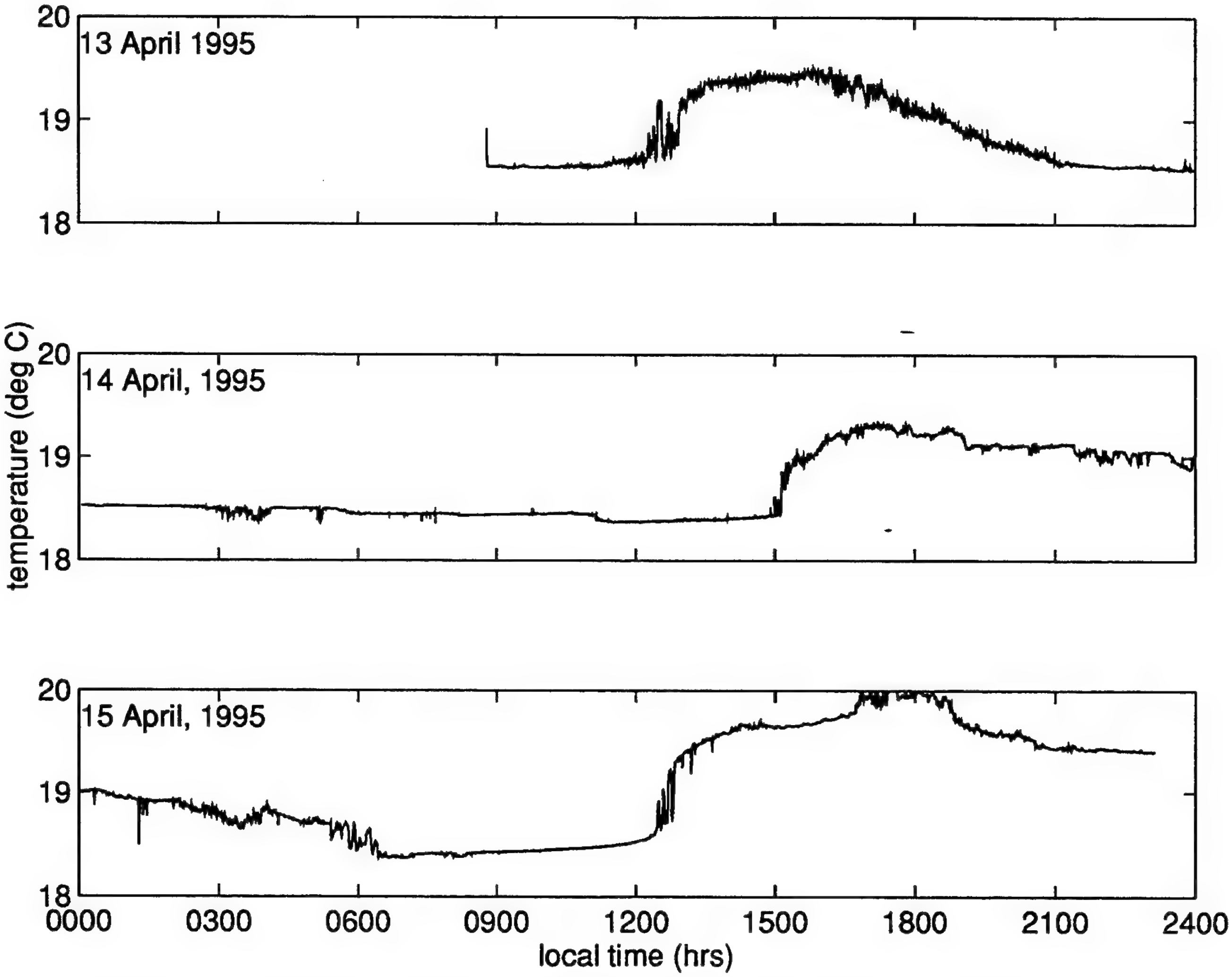


Figure 11. Temperature time series from CTD mounted on source tower for 13–15 April, 1995.

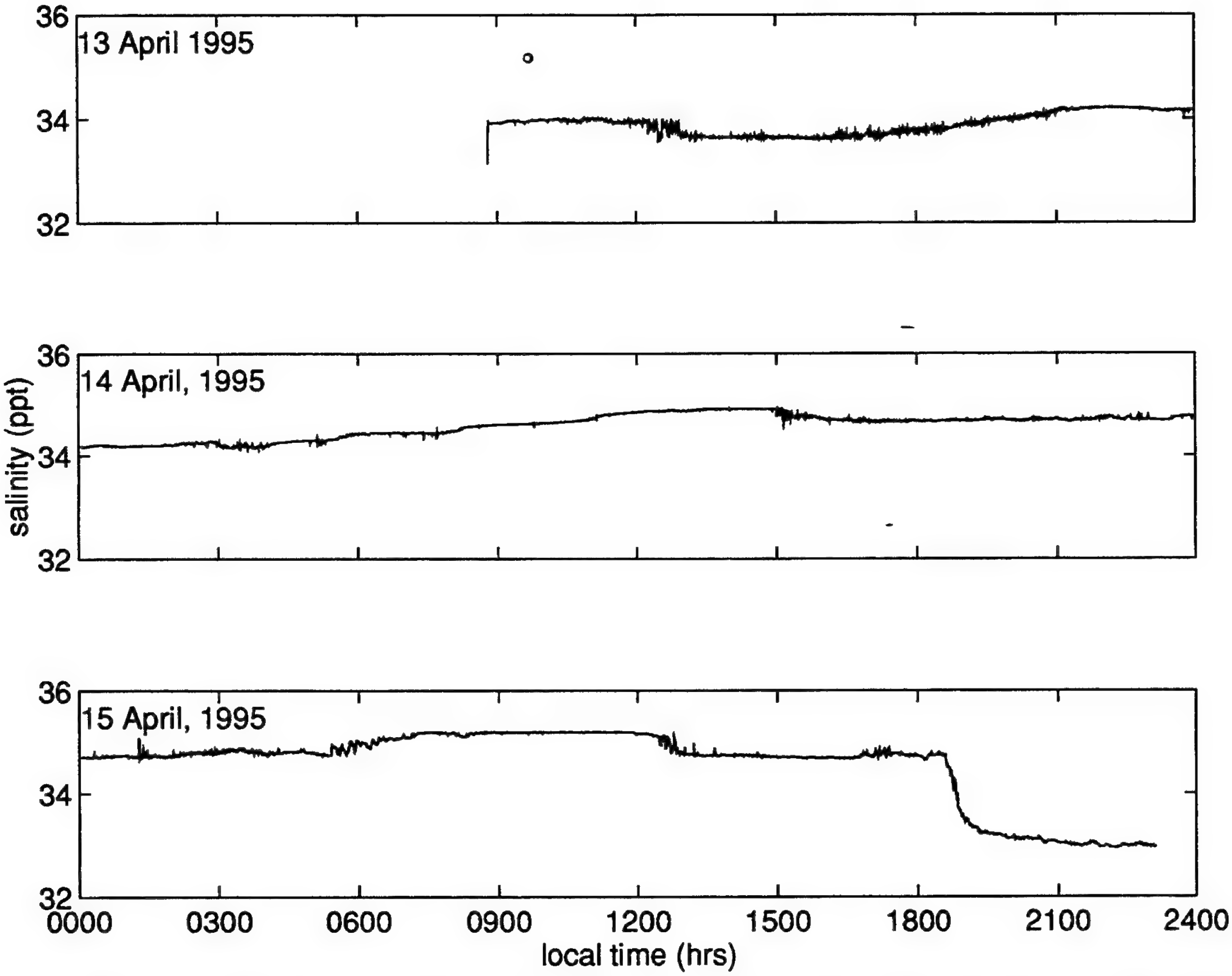


Figure 12. Salinity time series from CTD mounted on source tower for 13–15 April, 1995.

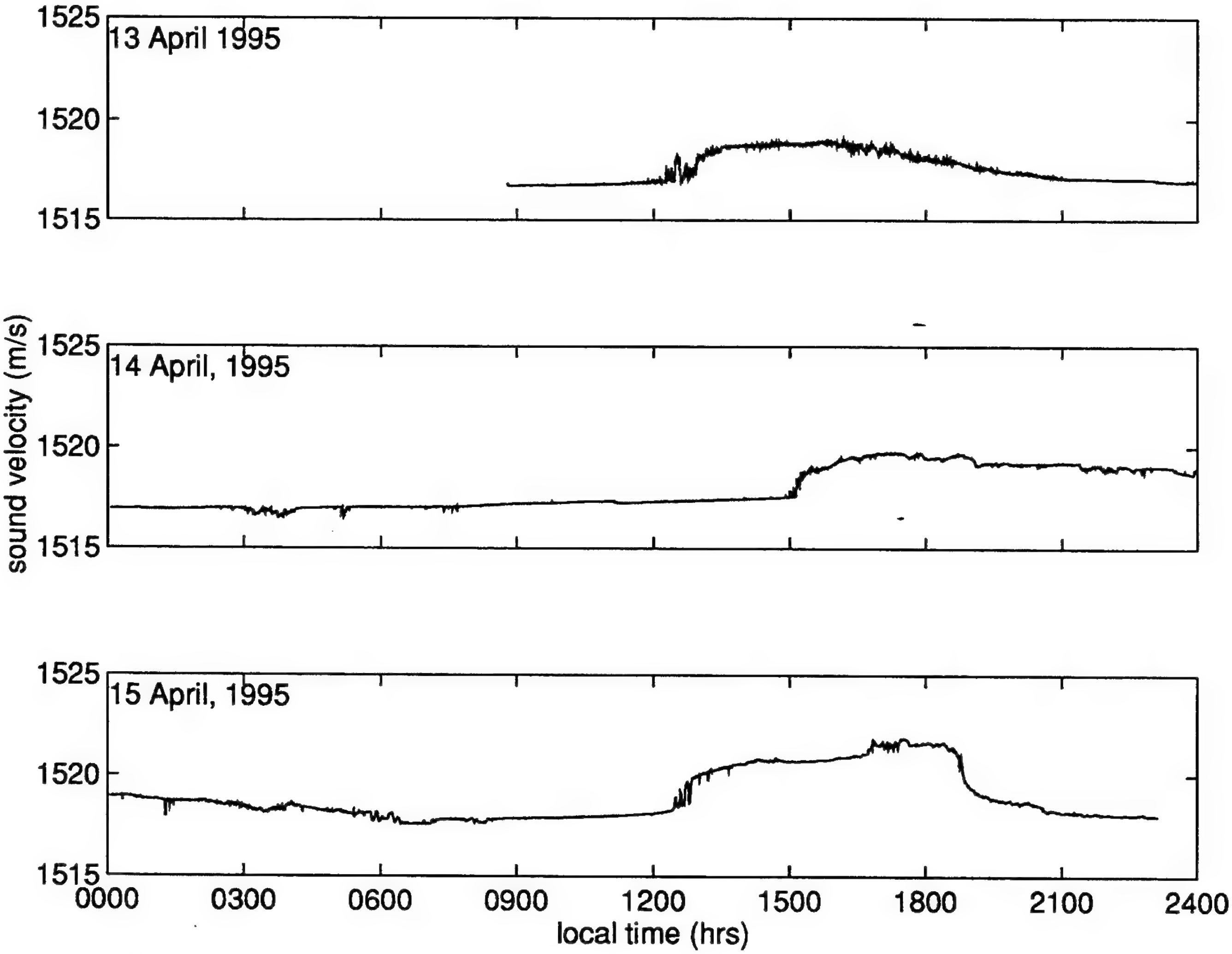


Figure 13. Sound velocity time series from CTD mounted on source tower for 13–15 April, 1995

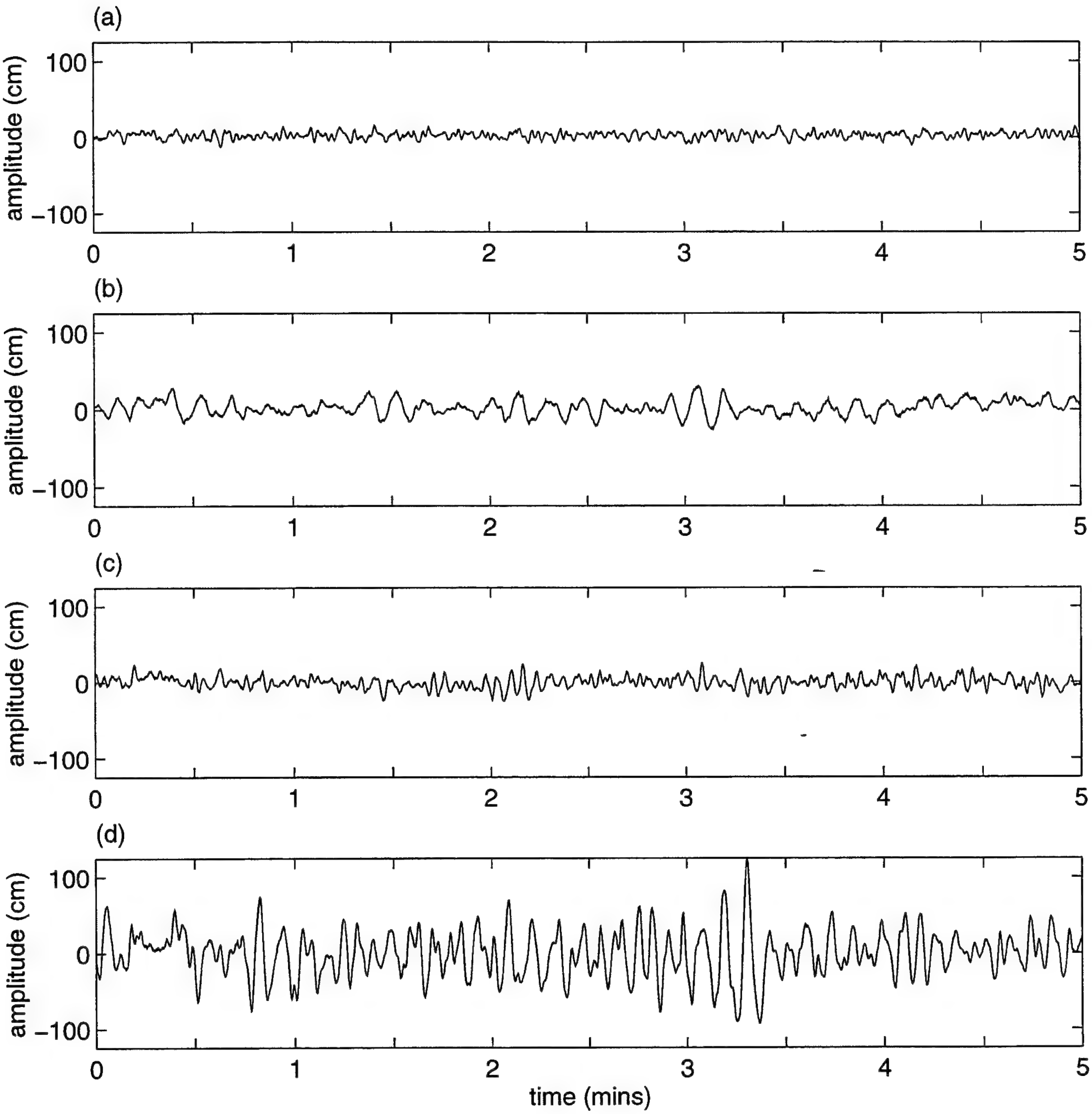


Figure 14. Waverider time series from (a) 30 March at 1622, (b) 5 April at 1631 (c) 10 April at 1653, and (d) 11 April at 1008.

Table 4. Waverider specifications.

Minimum noise peak-peak (1 Hz bandwidth)	0.02 m
Maximum wave height (twice max. amplitude)	40 m
Wave frequency range (amplitude accuracy)	0.035 Hz-0.65 Hz (30%)
	0.065 Hz-0.50 Hz (3%)
Horizontal sensitivity	< 3% of vertical
Maximum changes if -5° < water temp < +25°C	
Zero	< 0.5 m
Sensitivity	< 3 %

(on 30 March, 5-8 April and 10-11 April), resulting in 234 files, each approximately 5 to 10 minutes in length. Spectra of the ocean surface were calculated using a 1024 point FFT. Peaks in the spectra at very low frequencies (Figure15) are believed to be low amplitude system contamination.

D. Thermistor Data

TMMS was designed and built by NRL to measure high resolution, small scale temporal and spatial changes in the ocean temperature and conductivity. Twelve fast response (23 ms) thermistors were configured in a planar array. This array was deployed at the same depth as the maximum response axis of the acoustic source and receivers, with the array center approximately 4m above the bottom. The thermistor array was located at distances from 38 to 100 m north, northwest of the yellow acoustic receive tower (Figure 3); and about 26.2 m west of the transmit tower. At this distance from the acoustic measurements systems temperature data are almost certainly uncorrelated with acoustic data. Element spacings were designed to measure horizontal and vertical spatial correlation

Table 5. Data collection times and associated acoustic, TMMS, and Waverider file numbers.

DATE	LOCAL TIME	ACOUST.	TMMS	WAVE-RIDER	DATE	LOCAL TIME	ACOUST.	TMMS	WAVE-RIDER
3/30/95	1118	1	1	1	4/05/95	1817	45	63	55
3/30/95	1142	2	4	3	4/05/95	1824	46	64	56
3/30/95	1157	3	6	4	4/05/95	1832	47	65	57
3/30/95	1330	4	7	5	4/05/95	1844	48	66	58
3/30/95	1340	5	8	6	4/05/95	1852	49	67	59
3/30/95	1349	6	9	7	4/05/95	1859	50	68	60
3/30/95	1359	7	11	8	4/05/95	1906	51	69	61
3/30/95	1408	8	12	9	4/05/95	1919	52	70	62
3/30/95	1449	9	13	11	4/05/95	1926	53	71	63
3/30/95	1459	10	14	12	4/05/95	1933	54	72	64
3/30/95	1507	11	15	13	4/05/95	1940	55	73	65
3/30/95	1515	12	16	14	4/06/95	907	56	74	67
3/30/95	1622	13	24	20	4/06/95	915	57	75	68
3/30/95	1613	14	23	19	4/06/95	922	58	76	69
3/30/95	1603	15	22	18	4/06/95	931	59	77	70
3/30/95	1644	16	26	21	4/06/95	1008	60	78	71
3/30/95	1653	17	27	22	4/06/95	1015	61	79	72
3/30/95	1706	18	30	23	4/06/95	1023	62	80	73
3/30/95	1714	19	31	24	4/06/95	1031	63	81	74
4/05/95	1246	20	32	25	4/06/95	1040	64	82	75
4/05/95	1254	21	33	26	4/06/95	1047	65	83	76
4/05/95	1303	22	34	27	4/06/95	1053	66	84	77
4/05/95	1313	23	35	28	4/06/95	1219	67	85	78
4/05/95	1321	24	37	29	4/06/95	1227	68	86	79
4/05/95	1330	25	38	30	4/06/95	1234	69	87	80
4/05/95	1337	26	39	31	4/06/95	1243	70	88	81
4/05/95	1345	27	40	32	4/06/95	1302	71	89	82
4/05/95	1352	28	41	33	4/06/95	1309	72	90	83
4/05/95	1412	29	42	34	4/06/95	1320	73	91	84
4/05/95	1421	30	44	35	4/06/95	1327	74	92	85
4/05/95	1551	31	46	38	4/06/95	1334	75	93	86
4/05/95	1559	32	47	39	4/06/95	1342	76	94	87
4/05/95	1606	33	48	40	4/06/95	1354	77	95	88
4/05/95	1615	34	49	41	4/06/95	1402	78	97	89
4/05/95	1622	35	50	42	4/06/95	1409	79	98	90
4/05/95	1631	36	51	43	4/06/95	1416	80	99	91
4/05/95	1638	37	52	44	4/06/95	1424	81	100	92
4/05/95	1708	38	56	47	4/06/95	1430	82	101	93
4/05/95	1715	39	55	46	4/06/95	1437	83	102	94
4/05/95	1723	40	57	48	4/06/95	1447	84	103	95
4/05/95	1742	41	59	51	4/06/95	1454	85	104	96
4/05/95	1749	42	60	52	4/06/95	1502	86	105	97
4/05/95	1757	43	61	53	4/06/95	1509	87	106	98
4/05/95	1805	44	62	54	4/06/95	1516	88	107	99

Table 5 (cont.). Data collection times and associated acoustic, TMMS, and Waverider file numbers.

DATE	LOCAL TIME	ACOUST.	TMMS	WAVE-RIDER	DATE	LOCAL TIME	ACOUST.	TMMS	WAVE-RIDER
4/06/95	1525	89	108	100	4/08/95	1232	133	155	143
4/06/95	1532	90	109	101	4/08/95	1238	134	156	144
4/06/95	1538	91	110	102	4/08/95	1245	135	157	145
4/06/95	1546	92	111	103	4/08/95	1253	136	158	146
4/07/95	1353	93	112	104	4/08/95	1259	137	159	147
4/07/95	1400	94	113	105	4/08/95	1307	138	161	148
4/07/95	1407	95	114	106	4/08/95	1316	139	162	149
4/07/95	1414	96	115	107	4/08/95	1326	140	163	150
4/07/95	1421	97	116	108	4/08/95	1334	141	164	151
4/07/95	1428	98	117	109	4/08/95	1344	142	165	152
4/07/95	1438	99	118	110	4/08/95	1351	143	166	153
4/07/95	1445	100	119	111	4/08/95	1358	144	167	154
4/07/95	1500	101	120	112	4/08/95	1404	145	168	155
4/07/95	1507	102	121	113	4/08/95	1412	146	169	156
4/07/95	1514	103	122	114	4/08/95	1418	147	170	157
4/07/95	1520	104	123	115	4/08/95	1430	148	171	158
4/07/95	1527	105	124	116	4/08/95	1439	149	173	159
4/07/95	1537	106	125	117	4/08/95	1446	150	174	160
4/07/95	1543	107	126	118	4/08/95	1453	151	175	161
4/07/95	1551	108	127	119	4/08/95	1500	152	176	162
4/07/95	1558	109	128	120	4/08/95	1519	153	177	163
4/07/95	1605	110	129	121	4/08/95	1532	154	178	164
4/07/95	1612	111	130	122	4/08/95	1540	155	180	165
4/07/95	1619	112	131	123	4/08/95	1548	156	181	166
4/07/95	1631	113	132	124	4/08/95	1557	157	182	167
4/07/95	1638	114	133	125	4/08/95	1604	158	183	168
4/07/95	1645	115	134	126	4/08/95	1604	159	185	169
4/07/95	1653	116	136	127	4/08/95	1621	160	186	170
4/07/95	1700	117	137	128	4/08/95	1627	161	187	171
4/07/95	1708	118	138	129	4/08/95	1635	162	188	172
4/07/95	1716	119	139	130	4/08/95	1643	163	189	173
4/07/95	1722	120	140	131	4/08/95	1650	164	190	174
4/07/95	1730	121	141	132	4/08/95	1657	165	191	175
4/07/95	1738	122	142	133	4/08/95	1704	166	192	176
4/07/95	1745	123	143	134	4/08/95	1711	167	193	177
4/07/95	1758	124	145	136	4/08/95	1718	168	194	178
4/07/95	1808	125	146/147	137	4/08/95	1725	169	195	179
4/07/95	1818	126	148	138	4/10/95	1209	170	197	180
4/07/95	1825	127	149	139	4/10/95	1216	171	198	181
4/07/95	1831	128	150	140	4/10/95	1228	172	200	183
4/07/95	1838	129	151	141	4/10/95	1235	173	210	184
4/08/95	813	130	152	142	4/10/95	1247	174	202	185
4/08/95	822	131	153	142	4/10/95	1250	175	203	186
4/08/95	833	132	154	142	4/10/95	1258	176	204	187

Table 5 (cont.). Data collection times and associated acoustic, TMMS, and Waverider file numbers.

DATE	LOCAL TIME	ACOUST.	TMMS	WAVE-RIDER	DATE	LOCAL TIME	ACOUST.	TMMS	WAVE-RIDER
4/10/95	1305	177	205	188	4/11/95	1051	221	254	233
4/10/95	1313	178	206	189	4/11/95	1100	222	255	234
4/10/95	1321	179	207	190	4/11/95	1107	223	256	
4/10/95	1328	180	208	191	4/11/95	1114	224	257	
4/10/95	1336	181	209	192	4/11/95	1120	225	258/259	
4/10/95	1343	182	210	193	4/11/95	1225	226	260	
4/10/95	1351	183	211	194	4/11/95	1232	227	261	
4/10/95	1359	184	212	195	4/11/95	1238	228	262	
4/10/95	1408	185	213	196	4/11/95	1252	229	263/264	
4/10/95	1416	186	214	197	4/11/95	1305	230	266	
4/10/95	1519	187	219/220	199	4/11/95	1312	231	267	
4/10/95	1526	188	221	200	4/11/95	1318	232	268	
4/10/95	1533	189	222	201	4/11/95	1325	233	269	
4/10/95	1539	190	223	202	4/11/95	1332	234	270	
4/10/95	1549	191	224	203	4/11/95	1339	235	271	
4/10/95	1555	192	225	204	4/12/95	815	236	272	
4/10/95	1603	193	226	205	4/12/95	822	237	273	
4/10/95	1610	194	227	206	4/12/95	829	238	274	
4/10/95	1616	195	228	207	4/12/95	946	239	275	
4/10/95	1623	196	229	208	4/12/95	955	240	277	
4/10/95	1630	197	230	209	4/12/95	1020	241	278	
4/10/95	1640	198	231	210	4/12/95	1047	242	279	
4/10/95	1647	199	232	211	4/12/95	1056	243	280	
4/10/95	1653	200	233	212	4/12/95	1103	244	281	
4/10/95	1701	201	234	213	4/12/95	1112	245	284	
4/10/95	1707	202	235	214	4/12/95	1119	246	285	
4/10/95	1713	203	236	215	4/12/95	1246	247	286	
4/10/95	1720	204	237	216	4/12/95	1252	248	287	
4/10/95	1727	205	238	217	4/12/95	1259	249	288	
4/10/95	1734	206	239	218	4/12/95	1306	250	289	
4/11/95	856	207	240	219	4/12/95	1314	251	290	
4/11/95	903	208	241	220	4/12/95	1320	252	291	
4/11/95	910	209	242	221	4/12/95	1327	253	292	
4/11/95	918	210	243	222	4/12/95	1334	254	293	
4/11/95	925	211	244	223	4/12/95	1343	255	294	
4/11/95	932	212	245	224	4/12/95	1359	256	295	
4/11/95	942	213	246	225	4/12/95	1358	257	296	
4/11/95	951	214	247	226	4/12/95	1404	258	297	
4/11/95	1000	215	248	227	4/12/95	1417	259	298	
4/11/95	1006	216	249	228	4/12/95	1424	260	299	
4/11/95	1013	217	250	229	4/12/95	1432	261	300	
4/11/95	1024	218	251	230	4/12/95	1442	262	301	
4/11/95	1038	219	252	231	4/12/95	1449	263	302	
4/11/95	1045	220	253	232	4/12/95	1459	264	303	

Table 5 (cont.). Data collection times and associated acoustic, TMMS, and Waverider file numbers.

DATE	LOCAL TIME	ACOUST.	TMMS	WAVE-RIDER	DATE	LOCAL TIME	ACOUST.	TMMS	WAVE-RIDER
4/12/95	1505	265	304		4/14/95	1556	309	349	
4/12/95	1514	266	305		4/14/95	1602	310	350	
4/12/95	1522	267	306		4/14/95	1608	311	351	
4/12/95	1524	268	307		4/14/95	1615	312	352	
4/12/95	1533	269			4/14/95	1621	313	353	
4/12/95	1546	270	309		4/14/95	1630	314	354	
4/12/95	1557	271	310		4/14/95	1637	315	355	
4/12/95	1602	272	311		4/14/95	1644	316	356	
4/12/95	1616	273	313		4/14/95	1650	317	357	
4/12/95	1623	274	314		4/14/95	1657	318	358	
4/12/95	1633	275	315		4/14/95	1703	319	359	
4/12/95	1645	276	316		4/14/95	1709	320	360	
4/12/95	1651	277	317		4/14/95	1715	321	361	
4/12/95	1658	278	318		4/15/95	1214	322	362	
4/14/95	1215	279	319		4/15/95	1221	323	363	
4/14/95	1225	280	320		4/15/95	1227	324	364	
4/14/95	1234	281	321		4/15/95	1234	325	365	
4/14/95	1241	282	322		4/15/95	1243	326	366	
4/14/95	1249	283	323		4/15/95	1252	327	368	
4/14/95	1256	284	324		4/15/95	1259	328	369	
4/14/95	1304	285	325		4/15/95	1306	329	370	
4/14/95	1312	286	326		4/15/95	1312	330	371	
4/14/95	1319	287			4/15/95	1318	331	372	
4/14/95	1325	288			4/15/95	1325	332	373	
4/14/95	1332	289	327		4/15/95	1334	333	374	
4/14/95	1343	290	328		4/15/95	1342	334	375	
4/14/95	1350	291	329		4/15/95	1348	335	376	
4/14/95	1357	292	330		4/15/95	1354	336	377	
4/14/95	1404	293	331		4/15/95	1401	337	378	
4/14/95	1412	294	332		4/15/95	1408	338	379	
4/14/95	1419	295	333		4/15/95	1414	339	380	
4/14/95	1428	296			4/15/95	1421	340	381	
4/14/95	1434	297	334		4/15/95	1427	341	382	
4/14/95	1442	298	336		4/15/95	1437	342	383	
4/14/95	1449	299	337		4/15/95	1444	343	384	
4/14/95	1455	300	338		4/15/95	1450	344	385	
4/14/95	1502	301	340		4/15/95	1459	345	386	
4/14/95	1510	302	341		4/15/95	1506	346		
4/14/95	1517	303	342		4/15/95	1513	347	388	
4/14/95	1523	304	344		4/15/95	1519	348	389	
4/14/95	1529	305	345		4/15/95	1526	349	390	
4/14/95	1537	306	346		4/15/95	1532	350	391	
4/14/95	1543	307	347		4/15/95	1539	351	392	
4/14/95	1549	308	348		4/15/95	1545	352	393	

Table 5 (cont.). Data collection times and associated acoustic, TMMS, and Waverider file numbers.

DATE	LOCAL TIME	ACOUST.	TMMS	WAVE-RIDER	DATE	LOCAL TIME	ACOUST.	TMMS	WAVE-RIDER
4/15/95	1552	353	394		4/17/95	1447	396	438	
4/15/95	1558	354	395		4/17/95	1451	397	439	
4/15/95	1605	355	396		4/17/95	1501	398	440	
4/15/95	1612	356	397		4/17/95	1507	399	441	
4/15/95	1619	357	398		4/17/95	1514	400	442	
4/15/95	1625	358	399		4/17/95	1520	401	444	
4/15/95	1631	359	400		4/17/95	1534	402	445	
4/15/95	1630	360	401		4/17/95	1540	403	446	
4/15/95	1644	361	402		4/17/95	1548	404	447	
4/15/95	1651	362	403		4/17/95	1554	405	448	
4/15/95	1657	363	404		4/17/95	1600	406	449	
4/15/95	1703	364	405		4/17/95	1606	407	450	
4/17/95	809	365	406		4/18/95	751	408	451	
4/17/95	816	366	407		4/18/95	802	409	453	
4/17/95	823	367	408		4/18/95	809	410	454	
4/17/95	830	368	409		4/18/95	816	411	455	
4/17/95	837	369	410		4/18/95	822	412	456	
4/17/95	844	370	411		4/18/95	828	413	457	
4/17/95	850	371	412		4/18/95	836	414	458	
4/17/95	857	372	413		4/18/95	844	415	459	
4/17/95	904	373	414		4/18/95	851	416	460	
4/17/95	911	374	415		4/18/95	857	417	461	
4/17/95	917	375	416		4/18/95	903	418	462	
4/17/95	926	376	417		4/18/95	913	419	463	
4/17/95	932	377	418		4/18/95	919	420	464	
4/17/95	938	378	419		4/18/95	927	421	465	
4/17/95	945	379	420		4/18/95	934	422	466	
4/17/95	954	380	421		4/18/95	941	423	467	
4/17/95	1001	381	422		4/18/95	948	424	468	
4/17/95	1007	382	423		4/18/95	955	425	469	
4/17/95	1013	383	424		4/18/95	1001	426	470	
4/17/95	1020	384	425		4/18/95	1009	427	471	
4/17/95	1026	385	426		4/18/95	1015	428	472	
4/17/95	1032	386	427		4/18/95	1022	429	473	
4/17/95	1039	387	428		4/18/95	1028	430	474	
4/17/95	1345	388	429		4/18/95	1210	431	475	
4/17/95	1352	389	430		4/18/95	1219	432	476	
4/17/95	1353	390	431		4/18/95	1226	433	477	
4/17/95	1404	391	432		4/18/95	1232	434	478	
4/17/95	1420	392	434		4/18/95	1239	435	479	
4/17/95	1426	393	435		4/18/95	1245	436	480	
4/17/95	1432	394	436		4/18/95	1301	437	482	
4/17/95	1438	395	437		4/18/95	1307	438	483	
					4/18/95	1315	439	484	

Table 5 (cont.). Data collection times and associated acoustic, TMMS, and Waverider file numbers.

DATE	LOCAL TIME	ACOUST.	TMMS	WAVE-RIDER	DATE	LOCAL TIME	ACOUST.	TMMS	WAVE-RIDER
4/18/95	1321	440	485		4/19/95	1412	484	26	
4/18/95	1328	441	486		4/19/95	1419	485	27/28	
4/18/95	1335	442	487		4/19/95	1429	486	29	
4/18/95	1344	443	488		4/19/95	1435	487	30	
4/18/95	1354	444	490		4/19/95	1432	488	31	
4/18/95	1401	445	491		4/19/95	1451	489	32	
4/18/95	1409	446	492		4/19/95	1457	490	33	
4/18/95	1417	447	493		4/19/95	1503	491	34	
4/18/95	1423	448	494		4/19/95	1525	492	36	
4/18/95	1433	449	496		4/19/95	1536	493	37	
4/18/95	1440	450	497		4/19/95	1543	494	38	
4/18/95	1450	451	499		4/19/95	1549	495	39	
4/18/95	1457	452	500		4/19/95	1555	496	40	
4/18/95	1504	453	501		4/19/95	1602	497	41	
4/18/95	1512	454	502						
4/18/95	1518	455	503						
4/18/95	1525	456	504						
4/18/95	1532	457	505						
4/18/95	1538	458	506						
4/18/95	1545	459	507						
4/18/95	1558	460	0						
4/18/95	1605	461	1						
4/18/95	1611	462	2						
4/18/95	1618	463	3						
4/18/95	1624	464	4						
4/19/95	808	465	6						
4/19/95	815	466	7						
4/19/95	822	467	8						
4/19/95	830	468	9						
4/19/95	837	469	10						
4/19/95	843	470	12						
4/19/95	851	471	13						
4/19/95	857	472	14						
4/19/95	904	473	15						
4/19/95	912	474	16						
4/19/95	918	475	17						
4/19/95	927	476	18						
4/19/95	935	477	19						
4/19/95	942	478	20						
4/19/95	950	479	21						
4/19/95	957	480	22						
4/19/95	1003	481	23						
4/19/95	1011	482	24						
4/19/95	1405	483	25						

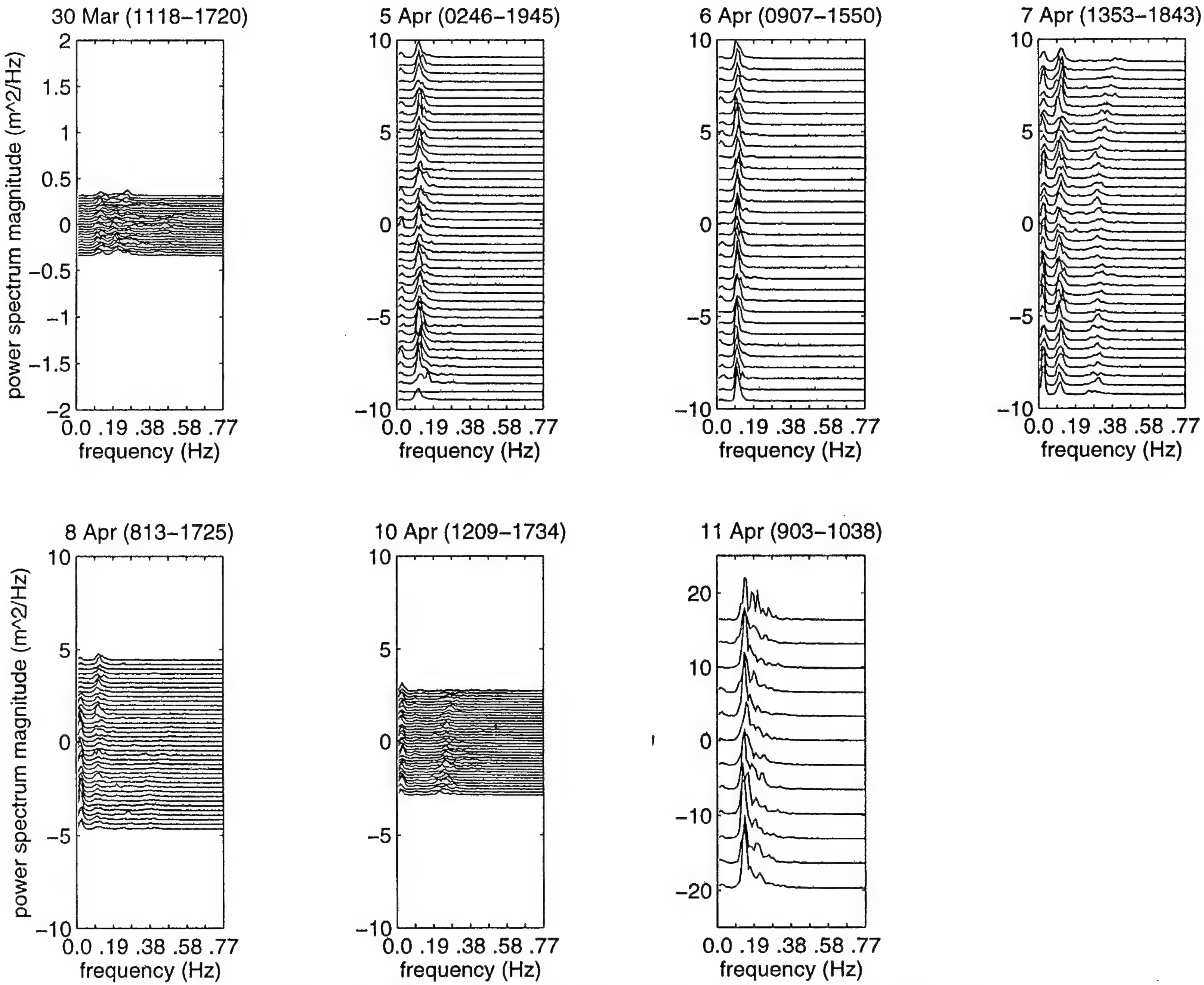


Figure 15. Wave spectra from Panama City Beach during acoustic runs.

lengths to slightly over 1 m. The thermistor system was 2 m on a side, with 6 thermistors placed along the vertical and horizontal axes (Figure 16). Thermistor spacings along the vertical and horizontal axes were 26.5, 35.5, 38.5, 39.5, and 41.5 inches from channels 1 and 4 respectively. The thermistors were sealed in solid glass rods. Conductivity sensors were mounted at each end of the horizontal array.

System calibrations were performed at the Naval Oceanographic Office (NAVOCEANO) calibration facility prior to the experiment. Temperature changes as small as 0.03°C can be resolved and absolute temperature accuracy is estimated at 0.1°C over a temperature range from 1° to 25°C. Conductivity accuracy is estimated as 0.001 mmho/cm. A photo of the TMMS system on the ship's deck after recovery is shown in Figure 17. Barnacles covered the entire structure but did not appear to cover the actual glass housings.

The sensor electronics, digitizing, and transmitting hardware were mounted in a pressure casing below the array. The casing was moored to the ocean bottom and a vane on the casing insured that the array remained perpendicular to the prevailing current direction. Data from each thermistor and conductivity sensor were sampled at 60 Hz. The data were cabled directly to the source tower and the digital stream was relayed to the shore station. During the course of the experiments it was determined that both channels 1 and 8 were inoperable (Fig 16). The TMMS data were monitored and recorded in real time on a dedicated computer during each acoustic run. A total of 497 runs were collected during 14 measurement days (Table 5). Approximately 75% of these files exhibit tempera-

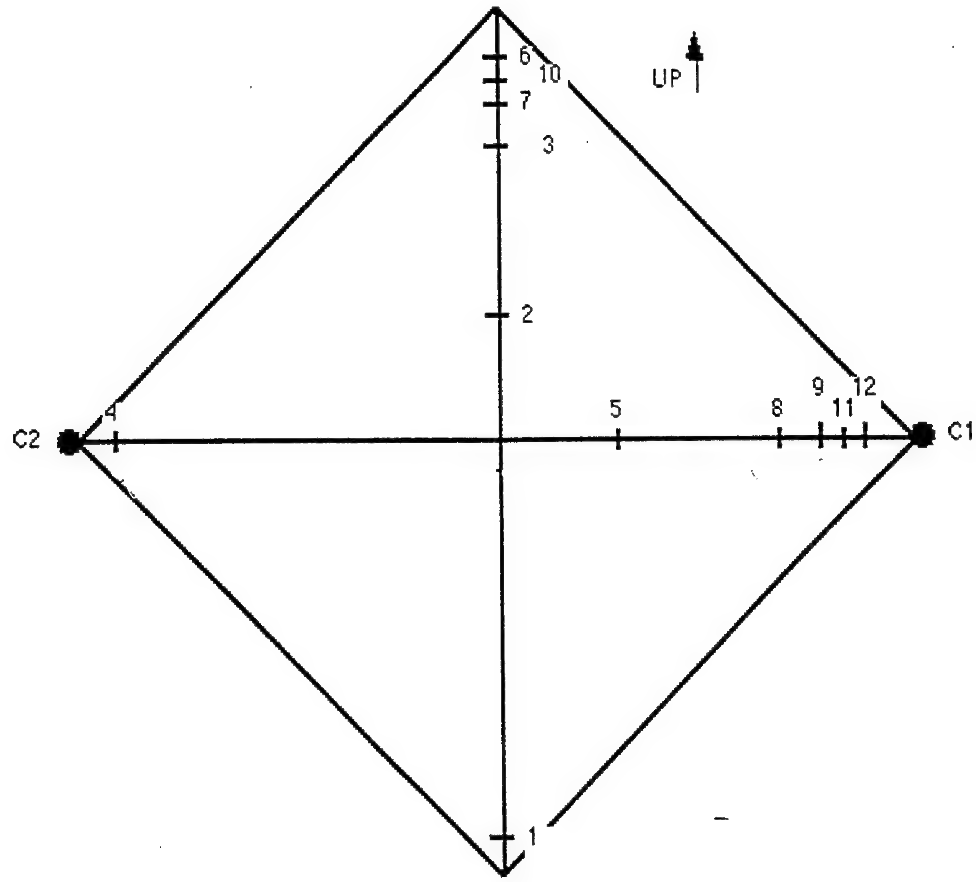


Figure 16. Schematic of TMMS array configuration.

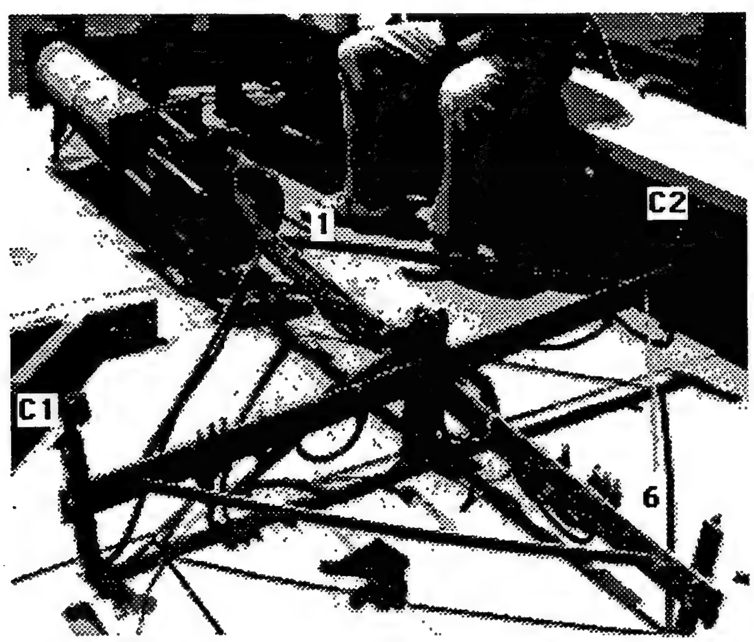


Figure 17. TMMS system.

ture fluctuations greater than 0.07°C. The analysis of these temperature data is continuing.

IV. ANALYSIS

Weather during acoustic data collection was typical of the northeastern Gulf Coast during spring. In general, air and sea temperatures increased over the course of the experiment except during the passage of two cold fronts on 30 March and 11 and 12 April. Days associated with the passage of cold fronts were characterized by cloudy, windy conditions and low barometric pressure (Fig. 4). Wind directions prior to the approaching front were generally from the east and southeast, switching abruptly to northwest or north after the frontal passage. Days with these atmospheric characteristics were 30 and 31 March, 5, 6 and 7 April, and 11 and 12 April. Passage of a cold front on 11 to 12 April produced average wind speeds in excess of 7.5 m/s and peak wind gusts up to 16 m/s for approximately one hour on the morning of the 12th. Gusts in excess of 7.5 m/s occur regularly for a 20 hour period from 1200 on 11 April to 0800 and 12 April. From 17 to 19 April a much weaker front approached the area. Wind direction maintained its southerly component while increasing in intensity, air temperatures remained stable, and atmospheric pressures dipped only slightly. Days between cold fronts are characterized by clear skies and local sea breezes which developed in the afternoon and continued into the early evening hours. These sea breezes were typically from the south or southwest and did not exceed 6 m/s. The air temperature over land dropped by several degrees once the sea breeze

was well established. Wave action on these days is predominately from swell with some wind waves (sea) being generated by the afternoon sea breeze. Days with these characteristics are 30 March, 1 to 4 April, 7 to 10 April, and 13 to 16 April.

Oceanographic conditions reflect the changes in the local atmospheric conditions. Spectra of the ocean surface revealed wave periods from 4 to 10 sec. On calm days, shorter period wind waves were typically associated with the development of an afternoon sea breeze.[8] Wave heights measured on 30 March were < 0.3 m (Fig. 14) and appear to be a combination of sea and swell (Fig.15). On 5 and 6 April (Figure 14) wave heights did not exceed 0.8 m and were primarily due to the 8-10 sec period swell (Figure 15). Wave action subsided on 8-10 April and again are a combination of small amplitude swell and wind waves. The cold front on 11 April produced wave heights in excess of 2.5 m.

Springtime warming of coastal water was evident in both the temperature profiles and time series. In general, the coastal water mass warmed from a low of 16.8° C on 6 April to 22.7° C on 19 April. Water column temperatures were close to isothermal and had not yet developed the typical late spring mid-depth thermocline. Measured salinities ranged from 31.8 to 35.3 ppt; typical values for a coastal water mass in this area. Subsurface salinities ranged from 0 to 2 ppt saltier than surface water.

On calm days, changes in the water mass at the measurement site associated with tidal flow through the inlets are indicated from the CTD time series (CTD located at mid water column depth). The best example of water

mass changes was obtained on 15 April (Figs. 11 and 12) and was associated with a predicted tidal range of 38 cm, the maximum predicted range we encountered during CTD measurements (Fig. 2). Gulf water at the measurement site has typical salinities of 35 ppt and is evident from approximately 0730 to 1200 local time. At 1220, water from the lower portion of St. Andrews Bay, having slightly lower values for salinity, passed the measurement site. Water of much lower salinity (33 ppt), presumably from the upper portions of St. Andrews Bay, passed the measurement site at 1900. Two other examples of presumed bay effluent reaching the measurement site are seen on 8 and 9 April (Figs. 8 and 9). In general, temperature time series indicate the bay water mass is from 1° to 1.5° warmer than the gulf water (Figs. 8 and 11). Salinity time series indicate the bay water mass is slightly less saline by 1 to 2 ppt (Figs. 9 and 12).

Moderate winds can produce a well mixed water column with properties between those of the open gulf and the bay.[2] CTD time series from 6 to 10 April indicate the water mass is well mixed on 7 April after two days of 5 to 6 m/s winds from the east. After the seas causing mixing have subsided, it took only one flood tide which occurred around 1500 local time on 7 April, to detect tidal flushing from the bay. Passage of the bay effluent at the measurement site is suggested from the salinity and temperature time series on 8 and 9 April. The approach and passage of another cold front produced easterly winds of greater intensity on 11 and 12 April. It is assumed that the water column characteristics on these days would be uniform. Winds subsided to less than 2.5 m/s by 1500 on 12 April and the next predicted flood tide occurred at 1948 on the 12th. CTD time series from

13 to 15 April suggest the normal water column characteristics had been reestablished at the measurement site. The small tidal range on the 13th (7 cm) produced only small changes in salinity as compared with the 15th. A third period of sustained southerly winds of varying intensity occurred from 16 to 20 April. No oceanographic time series were collected during this period, so water column characteristics are unknown.

Estuarine fronts formed by buoyant outflow from rivers and estuaries (plumes) have been reported by numerous authors.[2, 8-13] The plumes propagate seaward and are usually associated with a sharp change in water color which defines the leading edge of the front at the surface. There is a strong convergence zone along the frontal boundary and a downwelling of surface water that results in significant vertical mixing, often many meters deep. Fronts have been observed to occur at distances to a few tens of kilometers from the source and remain well defined for several hours. Internal wave activity and turbulent mixing (interfingering of water masses) are often associated with these frontal regions.[8, 9,11-15] From our CTD data, at least three occurrences of these phenomena were experienced at the measurement site during the measurement period (Figure 18). Each of these occurrences were on calm days (wind speeds less than 2.5 m/s) during an outgoing tide and appear to be associated with the movement of the tide line past the measurement site. The largest excursions in temperature and salinity occurred on the 9th while those associated with internal waves on the 14th and 15th are of lesser amplitude. These oceanographic

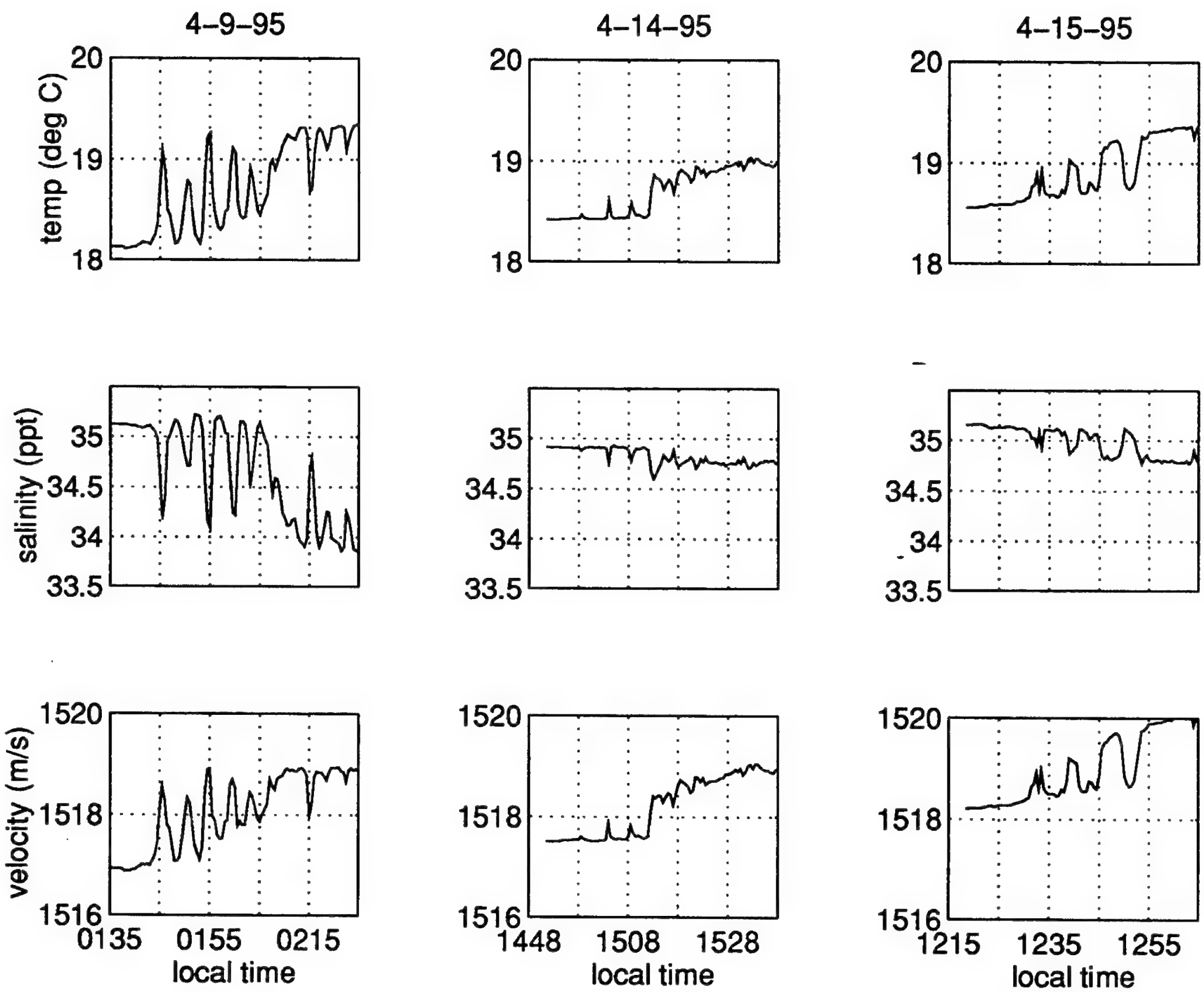


Figure 18. CTD data indicating internal wave activity.

events had periods on the order of 5 mins (0.003 Hz) and were approximately 20 to 30 minutes in duration.

The Brunt-Väisäla frequency is an often used measure of water mass stability. It represents the simple harmonic frequency at which a water mass could oscillate given a particular density gradient. The larger the density gradient, the faster the oscillation. Due to the sensitivities of the pressure sensor and uncertainties in density, the frequency can only be estimated from the sound speed profiles. This coastal water mass vertical density structure could not support frequencies above 0.02 Hz. The estimated frequency range is 0-30 cycles/hour (0-0.01 Hz) on 13 and 14 April, and 0-60 cycles/hour (0-0.02 Hz) for all other measurement days. These frequencies imply an upper limit to the internal wave frequency and are consistent with the internal wave periods shown in Figure 18.

V. SUMMARY

Environmental measurements of both atmospheric and oceanographic conditions were collected during NRL's high frequency acoustic coherence experiments conducted in the very shallow waters off of Panama City Beach during March and April 1995. From 30 March to 22 April wind speed and direction, air temperature, barometric pressure and solar irradiation were collected every 15 minutes. Oceanographic measurements were taken as sea conditions permitted from 5 April to 19 April. A total of 29 CTD profiles and two

CTD time series of 3 and 4 days each were collected. Wave spectra and small scale temperature variations were also collected during each acoustic run.

Weather and oceanographic conditions were typical of the northeastern Gulf of Mexico during spring. In general, air and sea temperatures rose over the course of the experiment except during the passage of cold fronts. Cold fronts passed through the area approximately every five days producing strong winds and well mixed oceanographic conditions which persist for only a short time once wind conditions subside. Two cold fronts passed through during the experiment and a third appears to have approached the area late in the experiment. Water column temperatures were close to isothermal and had not developed the typical late spring mid-depth thermocline. However, changes in the water mass produced by effluent from St. Andrews Bay during falling tides were evident on calm days in the temperature, salinity, and sound speed time series. On at least three occasions, internal wave activity was also associated with these water mass changes.

ACKNOWLEDGMENTS

A project of this scope and magnitude would not be possible without the support of many individuals. Key personnel involved in planning and execution of this project include Dr. Steve Stanic and Ted Kennedy (NRL), Robert Brown (Neptune, Inc.) and Richard Smith (Planning Systems, Inc). This analysis also benefited from our conversations with Dr. Ralph Goodman (Applied Physics Laboratory/Penn State), and Dr. Don Johnson (NRL).

REFERENCES

1 R. Smith, S. Stanic, and E. Kennedy,"High-frequency acoustic phase stability measurement system," Proc. IEEE Ocean's 95 (**2**) 1311-1318, 1995.

2 G.G.Salsman and A.J. Ciesluk,"Environmental conditions in coastal waters near Panama City Florida," Naval Coastal Systems Center, NCSC TR-337-78, Aug 1978.

3 "Tide Tables 1995 High and Low Water Predictions East Coast of North and South America, including Greenland," US Department of Commerce, NOAA, 1994.

4 "Tide Current Tables 1995 Atlantic Coast of North America," US Department of Commerce, NOAA, 1994.

5 George B.Dowling,"Low frequency shallow water internal waves at Panama City, Florida," U.S. Navy Mine Defense Laboratory, MDL 313, Nov 1966.

6 Donald L.Durham and Robert O. Reid, "Analysis of tidal current observations over the northeastern shelf of the Gulf of Mexico," Texas A&M University, A&M Project 286 Ref: 67-I-T, April 1967.

7 Christine T. Mire,"Indications of Environmental Drivers for High Frequency Phase Fluctuations", Master of Science Thesis for University of New Orleans, Aug 1995.

8 Richard W. Garvine and John D. Monk, "Frontal structure of a River Plume", *J. of Geophyical Res.* **79** No. 15, 2251-2259, May 1974.

9 Richard W. Garvine, "Radial spreading of buoyant, surface plumes in coastal

waters", *J. of Geophyical Res.* **89** No. C2 1989-1996, March 1984.

10 David A. Luketina and Jorg Imberger, "Characteristics of a surface buoyant jet", *J. of Geophyical Res.* **92** No. C5 5435-5447, May 1987.

11 Richard P Stumpf, Guy Gelfenbaum, and Jonathan R. Pennock, "Wind and tidal forcing of a buoyant plume, Mobile Bay, Alabama", *Continental Shelf Research* 13 No. 11 1281-1301, 1993.

12 John L. Largier, "Estuarine fronts: How important are they?", *Estuaries* 16 No. 1, 1-11, March 1993.

13 Charles C. Sarabun, Jr., "Observations of a Chesapeake Bay tidal front", *Estuaries* 16 No. 1, 68-73, March 1993.

14 J. Wu,"Mixed region collapse with internal wave generation in a density-stratified medium", *J. Fluid Mech.* **35**, 531-544, 1969.

15 R. Amen and T. Maxworthy, "The gravitational collapse of a mixed region into a linearly stratified fluid", *J. Fluid Mech.* **96** part 1, 65-80, 1980.